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Pacific Hake Characteristics Affecting the Conduct of an Acoustic Clutter Experiment off the West Coast of the United States

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14. ABSTRACT

The Office of Naval Research is sponsoring an experiment off the Washington and Oregon coasts during the summer of 2012 that is designed to obtain acoustic clutter statistics from biological targets. Marine mammal regulations will restrict mid-frequency acoustic sources to water depths greater than 200 m. Pacific hake is a very abundant semi-pelagic fish species that is concentrated near the shelf break from northern California to British Columbia during the summer in very large aggregations. It is highly probable that Pacific hake will be encountered during the experiment. Therefore, in preparation for the experiment, the characteristics of Pacific hake that are pertinent to the experiment have been examined. These characteristics include abundance, summertime geographical distribution, depth distribution, size distributions of individual hake, sizes of hake aggregations, and spacings between aggregations. This report contains the results of this examination. In addition, the Pacific hake fishery in Washington and Oregon waters is described.

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Biological clutter; Fish aggregations; Pacific hake

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PACIFIC HAKE CHARACTERISTICS AFFECTING THE CONDUCT OF AN ACOUSTIC CLUTTER EXPERIMENT OFF THE WEST COAST OF THE UNITED STATES

INTRODUCTION

Fish can adversely affect the performance of Naval active sonar systems. Widely dispersed fish can cause reverberation that can mask target echoes. Groups of fish can produce echoes that can cause clutter or be mistaken for targets. The Office of Naval Research (ONR) is sponsoring an experiment off the West Coast of the United States during Summer 2012 as part of an effort to mitigate the effects of clutter caused by schooling fish. The clutter experiment will be conducted by personnel from the Naval Research Laboratory (NRL) in Washington, DC.

From an environmental standpoint, the primary requirement for a successful acoustic experiment involving scattering from fish is a dependable supply of fish. Criteria for a species to be considered as a dependable scatterer include abundance, known geographic distribution, and ease of insonifying the fish and interpreting the results. For example, fish living on or very near the bottom might be plentiful but separating returns scattered from the fish from those scattered from the bottom could be very difficult. Generally, abundance is the primary criterion to consider.

Pacific sardine (*Sardinops sagax*) and Pacific hake (*Merluccius productus*) (also known as Pacific whiting) are by far the two most abundant fish species off the West Coast at this time. [1] Pacific sardines form dense schools while Pacific hake are usually in large aggregations. For a clutter experiment, compact schools are preferable and a study of the pertinent characteristics of the Pacific sardine population off the West Coast has been completed. [1]

During recent summers, sardines have generally been in waters along the Washington and Oregon coasts. Most have been in the upper 20 to 30 m between 10 and 30 nm from shore in water depths that are usually no deeper than 100 or 200 m. [1] Because of limitations imposed by marine mammal regulations, the NRL measurement system must be positioned off the continental shelf and look shoreward. [2] Hake usually can be found near the shelf break off Washington and Oregon during the summer. [3]

Aggregations of fish can be expected to be non-uniform, or patchy, at some scale. [4] A large aggregation of fish, if spatially non-uniform, can generate local clutter-like responses. So, if hake

aggregations are patchy, they could generate strong, spatially compact, clutter returns. In addition, some portion of planned NRL measurements will consist of very long (30 s, 60 s) FM and Doppler-sensitive signals. The fact that the hake swim could be a useful test of the ability of long Doppler-sensitive signals to identify non-stationary scatterers. [5]

Since Pacific hake inhabit waters where the NRL measurements will be made and since the echoes from aggregations of hake may provide useful clutter data, this report addresses the characteristics of Pacific hake that are pertinent to a summertime acoustic clutter experiment off the West Coast. These characteristics include abundance, summertime geographic distribution, depth distribution, size distributions of individuals, and aggregational characteristics. The best source for information on these characteristics is the fisheries research community.

GENERAL CHARACTERISTICS OF THE PACIFIC HAKE STOCK

The coastal stock of Pacific hake typically ranges from southern California (25°N) to southern Alaska (55°N). [6] There are also smaller, genetically distinct, populations in the Strait of Georgia, Puget Sound and the Gulf of California. Only the coastal stock is considered here.

Pacific hake is a semi-pelagic species. In fishery management it is grouped with groundfish. As the most abundant groundfish off the U.S. West Coast, it is the object of an intense fishery. [3] Hake can live more than 15 years and can grow to 90 cm. However, very few fish grow to that size. Males mature when they are three years old and almost 30 cm long. Females mature at three to four years and about 35 to 40 cm long. [7] (Biologists studying Pacific hake use "fork lengths", which are measured from the tip of the snout to the "fork" in the tail. Navy acousticians and recreational fishermen tend to use "total lengths", which are measured from the tip of the snout to the tip of the tail. For Pacific hake, fork length is about 98% of total length. For most hake, this difference is a centimeter or less and, therefore, will be ignored.)

Hake spawn off south-central California from January through March. However, the actual spawning area and spawning behavior are ill-defined. [6] In the spring, adult hake migrate onshore and to the north to feed during the summer and fall along the continental shelf and slope from northern California to Vancouver Island. Older hake migrate farther north and have a greater latitudinal spread the younger hake. [6, 8] Also, during El Nino episodes (warm ocean conditions) a larger than normal fraction of the stock migrates into

Canadian waters. [8] Conversely, during La Nina episodes (cold conditions) there is a southward shift in hake distribution, which results in a smaller than normal fraction of the stock in Canadian waters. [8] Adults migrate back in offshore waters to the spawning area in November and December. Juveniles remain off California throughout the year. [6, 8]

Pacific hake are both major predators and prey in the Eastern Pacific Ocean. [6] Adult hake feed on euphausiids, pelagic schooling fish, such as Pacific herring, and, sometimes, juvenile hake. They are prey for many species, including lingcod and Humboldt squid.

THE PACIFIC HAKE FISHERY

Pacific hake are fished from northern California to British Columbia during the summer and fall. The fishery was essentially non-existent until 1966, when foreign factory trawlers began fishing. Joint venture U.S.-foreign and Canada-foreign fisheries began in 1978. All foreign fishing in U. S. waters ended in 1991. A small joint venture Canada-foreign fishery still continues. [3]

Pacific hake are caught with mid-water trawls, with most fishing occurring over the outer continental shelf and slope. Three techniques are used for catching and processing hake: factory trawlers, which catch and process the hake aboard; trawlers that deliver their catches to "mother" ships for at-sea processing; and trawlers that deliver their catches ashore for processing. In the U.S., 34% of the catch is allocated to factory trawlers, 24% to trawler/motherships, and 42% to shore-based trawlers. [3] There is also a small tribal hake fishery. The at-sea fishery for hake opens on May 15 and the primary shore-based fishery opens on June 15. [3]

There are currently ten factory trawlers licensed to fish for hake in U.S. waters but only six or seven have actually been fishing. [9] These vessels also fish for pollock in the Gulf of Alaska. Their lengths range from about 280 to 380 ft (85-115 m). There are six motherships and 35 catcher vessels licensed in the U.S. [10] The factory trawlers and motherships are all based in Seattle. In 2011, there were 54 shore-based trawlers licensed to fish in Oregon [11] and less than 20 in Washington. [10] The trawlers supplying motherships are generally larger than shore-based trawlers. Lengths for the catcher vessels range from about 60 to 150 ft (18-46 m), while lengths for shore based vessels range from 40 to 95 ft (12-30 m). [10]

The Canadian fishery is usually concentrated off the southern coast of Vancouver Island, south of 49°N. The Canadian domestic fishery is totally shore-based. [3]

PACIFIC HAKE ABUNDANCE

The primary goal of most fisheries research is the determination of abundance of commercially important fish species. Accurate abundance information provides a scientific basis for stock management. In the determination of abundance, much supporting information is obtained. This includes seasonal geographic distributions, depth distributions, and individual size and age distributions. Aggregational characteristics do not affect abundance estimates of many species and are frequently not reported.

The Pacific hake fishery is a major fishery in both the United States and Canada. In recent years a Joint Technical Committee (JTC) comprised of U.S. and Canadian scientists has conducted an annual stock assessment of Pacific hake to provide information for managing the stock in the upcoming year. The assessments are presented to the Pacific Fishery Management Council (PFMC), whose members represent various fishing industry groups and government agencies, for final approval. [e.g. 3, 12-14] The assessments use a combination of fishery data and fishery independent data.

In the 2009 and 2010 stock assessments, the fishery data included commercial catch statistics from the U. S. and Canada since 1966 and length and age-length compositions of the catches. Length compositions included U.S. data since 1975 and Canadian data since 1988. The primary non-fishery data were biomass indices and length and age-length compositions obtained on joint U.S. and Canadian echo sounder/trawl surveys. [12, 13]

In 2011 the stock assessment process was modified. Measured length and age-length compositions were eliminated. They were replaced by measured age compositions and mean weights at both length and age and mean lengths at age. The means were calculated from both fishery and survey data since 1975. [14] The consequence of this modification is that hake lengths measured in any given year are no longer used directly in the assessment process.

Echo sounder/trawl surveys of hake have been conducted by the National Marine Fisheries Service (NMFS) since 1977 to assess the distribution, abundance and biology of Pacific hake. Between 1977 and 2001, surveys were conducted every three years. Since 2001, they have been conducted every two years. [15-20] PFMC has recommended that surveys be conducted annually to improve the accuracy of hake abundance estimates. [3] There will be an NMFS hake survey in 2012. [20]

The echo sounder/trawl method uses echo sounders to measure the total acoustic backscattering strength along a track at different frequencies. The tracks are oriented east-west, nominally 10 nm

apart. Since 1995 the tracks have covered depths from 50 to 1500 m. Trawls near the track lines provide information on the species and sizes of fish causing the backscatter. Equations relating the target strength of an individual fish to its size are used to calculate the numbers or weight of fish along a track from total backscattering strength. Then a biomass index is calculated.

Commercial catch data, biomass indices from the NMFS hake surveys and biological data from both the commercial catches and NMFS trawls are combined in a variety of models to produce abundance estimates. The models, which are being improved continually, use time series of data, so that any changes in the models or data change not only the estimate for the current year but also for previous years.

Figure 1 shows annual catches of Pacific hake since 1991, the first year that the U.S. eliminated joint-venture fishing. A 1997 agreement allocates 73.88% of the total catch of Pacific hake to the U.S. and 26.12% to Canada. [3] Since 1991 there have been several peaks and valleys in the U.S., Canadian, and total catches. The total catch has varied between about 200,000 and 350,000 mt; the U.S. catch between about 150,000 and 25,000 mt; and the Canadian catch between about 50,000 and 1000,000 mt. Total U.S. and Canadian catches generally parallel each other between 1991 and 2000; after 2000 they do not.

(It should be noted that the total U.S. catch of hake shown in Figure 3 of Ref. 1 is incorrect. [20] For most species, where the total catch is landed ashore, the terms "catch" and "landings" are synonymous. However, for hake, where much of the catch is processed at sea, they are quite different. The curve in Ref. 1 includes only those fish landed ashore. It matches the U.S. shore-based curve in Figure 1.)

The catch numbers for hake may not accurately mirror abundances due to bycatch limitations. (Bycatch is the term for the incidental capture of non-targeted species.) Recently, catches of hake have been restricted to below the optimum levels due to bycatch constraints for Chinook salmon and several depleted species of rockfish. There is anecdotal evidence that fishermen are avoiding areas of high historical bycatch and aggregations of larger hake to minimize bycatch of rockfish. [3]

Figure 2 shows the acoustically determined biomass index for the NMFS hake surveys from 1995 to 2011. [3] Due to the areal limitations of the surveys, the biomass index is a relative, not an absolute measure of abundance, but it plays a major role in abundance estimation. The biomass index determined during 2011 was by far the lowest since the surveys began.

Because the spawning area for hake is ill-defined, there has never been an attempt to survey hake eggs and larvae. Also, there is currently no approved method for estimating numbers of juvenile hake. Between 1999 and 2009, NMFS and the Pacific Whiting Conservation Cooperative (PWCC) conducted trawl surveys targeting juvenile hake but the results showed poor correlation with estimated year-class strengths based on catches of adults in subsequent years and the program was stopped. [3] The NMFS echo sounder/trawl surveys have focused on fish age two or greater. Age-1 hake are generally more southerly and closer to shore than adults and the trawl net is not optimum for the smaller fish. Nevertheless, some age-1 hake have been caught and techniques are being developed to use the limited age-1 data. [3] Because hake eggs and juvenile hake are not counted in any way, the size of a year class must be estimated after the fact based on the numbers determined when they reach age-2 or more. [3] Figure 3 shows the numbers of age-0 juveniles estimated by the 2009 through 2012 hake assessments. [3, 12-14] Since the estimates are based on time series of data, any changes made in a given year propagate backward in time. The effects of these changes diminish in earlier years, so that all four estimates for 1998 through 2004 are very similar. All assessments agree that the 1999 year class was exceptionally large and that there was a moderate year class in 2003. The 2009, 2010 and 2012 assessments agree that the 2005 and 2006 year classes were moderate but the 2011 estimate for these years is much higher. The 2009 and 2010 assessments were based on the 2007 and 2009 NMFS surveys and, so, had no information on the 2008 year class. [12, 13] The only additional information that the 2011 assessment had on the 2008 year class was data on age-2 hake from the fishing industry. Based on these data, the 2011 assessment estimated that the 2008 year class was extremely large. This, in turn, forced the 2011 estimates of the 2005 and 2006 year classes to be significantly higher than in the 2009 and 2010 assessments. [14] The 2012 assessment, which had data from the 2011 NMFS hake survey, determined that the 2008 year class was quite large, but not nearly as large as the 2011 assessment estimated. Hence, the 2005 and 2006 year classes were also not as large as the 2011 assessment had estimated. [3]

Figure 4 shows the female spawning stock biomass since 2000 as estimated by the 2009 through 2012 stock assessments. [3, 12-14] The 2011 assessment used two models that gave comparable estimates; these were averaged to produce a single result. The 2009, 2010 and 2011 assessments include the biomass of both the female spawning stock and the total adult stock, but the 2012 assessment gives only the female spawning stock. A comparison of the two stocks

for 2009 through 2011 shows that females make up almost half (48%) of the total adult stock. Thus, the total adult stock is approximately twice that shown in Figure 4.

Stock size estimates for the 2009 and 2010 assessments are very similar. All four assessments show the influence of the 1999 year class. The stock increases through 2003 as the 1999 year class matures and then steadily declines as that year class is depleted by fishing, predation and other natural causes. The 2011 stock size estimate diverges widely from the others after 2007 but the 2012 estimate is back in line with the earlier estimates. The cause of the divergence of the 2011 stock size estimate is the erroneously large estimate of the size of the 2008 year class.

If the 2011 assessment is excluded, Figure 4 indicates that the female spawning stock has been about 500,000 mt since 2007. Therefore, the adult stock of Pacific hake has been about 1,000,000 mt since 2007.

The error in the estimation of the size of the 2008 year class in the 2011 assessment caused the estimation of the adult stock size in 2011 to differ from those in 2009, 2010 and 2012 by about a factor of four. The stock size estimate is a major component of the process of setting fishing quotas. It is no wonder that the members of the JTC who conduct the annual assessments and the managers of the PFMC both recommend that NMFS conduct echo sounder/trawl surveys for hake annually and that an index for age-1 hake be developed.

PACIFIC HAKE SIZE

The size distribution of the stock of Pacific hake is determined by the ages of dominant year classes. The rate of growth of different year classes varies due to environmental conditions and population density, so there is a widespread difference in age/length, age/weight, and length/weight relationships among year classes. [21] The growth of hake has changed significantly in the last two decades. Prior to 1990 fish larger than 55 cm were relatively common; now few fish reach that size. [3] Table 1 shows median lengths versus age of Pacific hake as a function of gender and time period. [14] Young females and males are about the same size but at age four and above females are longer. Hake of age six and younger are about the same lengths for the 1975-1989 and 1990-2010 time periods. At higher ages the 1975-1989 hake continue to grow through age 15, while the 1990-2010 hake essentially stop growing after age 10.

Adult weights can not be cleanly separated into two time periods. Although the average weights of 45-50 cm long hake were relatively high from 1976 to 1981, they were also high from 2000 to

2002 and 2008 and 2009. Also, although weights were relatively low from 1989 to 1999, they were also low in 1983, 1986, 1987 and 2004 to 2006. [14]

Adult weights also vary throughout the year. They are at a minimum in April, after spawning; then climb during the summer feeding season to a maximum in September. Weights decrease slowly during the fall and more rapidly during the January through March spawning season. [14] There is a 20-25% weight gain over the summer.

The relationship of hake weight (W) in grams to its length (L) in cm as measured during the 2011 NMFS survey was approximately [20]

$$W = 0.0066\ (L)^3.$$

This equation gives the following:

for L = 20 cm,	W = 53 gm,
for L = 25 cm,	W = 103 gm,
for L = 30 cm,	W = 178 gm,
for L = 35 cm,	W = 283 gm,
for L = 40 cm,	W = 422 gm,
for L = 45 cm,	W = 601 gm,
for L = 50 cm,	W = 825 gm,
for L = 55 cm,	W = 1098 gm.

The results of the NMFS hake surveys illustrate how the size distribution of the hake stock has varied from 2001 through 2011. [15-20] The earlier years correspond to the time that the 1999 year class dominated the stock. In 2001 the size distribution had two peaks. There was a strong peak at 34 cm produced by the 1999 year class. There was also a much weaker, broader peak of age-3 to age-8 fish around 45 cm. [15] In 2003 the 1999 year class produced a strong, sharp peak at about 43 cm. There was also a much, much weaker peak at about 47 cm, produced primarily by age-7 and age-8 fish. [16] In 2005 the 1999 year class produced a strong peak at 44 cm and the 2003 year class produced a weaker peak at 34 cm. [17] In 2007 the 1999 year class still produced the strongest peak at 47 cm. There were also relatively strong peaks at 31 and 19 cm, produced by the 2005 and 2006 year classes, respectively. [18] In 2009 there was a strong peak at 39 cm produced by age-3 and age-4 fish of the 2005 and 2006 year classes. This peak had a shoulder between about 45 and 50 cm that was produced by age-6 and the dwindling population of age-10 fish. [13] In 2011 there was a strong peak at 40 cm produced by age-3 and age-2 fish of the 2008 and 2009 year classes. This peak had a weak shoulder between 45 and 50 cm produced by age-4 to age-6 fish. [3, 20] There was also a weaker peak at about 25 cm that would correspond to age-1 fish but survey results do not show

any of that age. [3, 20] The 1999 year was essentially gone from the stock in 2011. When peaks were produced by a single year class, the widths of the peaks were generally about 10 cm. The one notable exception was in 2001, when the width of the peak produced by the 1999 year class was only about 7 cm wide.

It can be projected that, based on the results of the 2011 NMFS hake survey, during the summer of 2012, most of the hake biomass will be from the 2008 year class, with a significant contribution from the 2009 year class. These age-4 and age-3 fish can be expected to have average lengths of 39 to 43 cm.

SUMMERTIME GEOGRAPHIC DISTRIBUTION OF PACIFIC HAKE

The north-south distribution of Pacific hake along the West Coast of North America during the summer is driven by two factors. The first is the size distribution of the hake in the stock. The second is related to the subsurface flow of the California Current and upwelling conditions, which are closely related to El Nino and La Nina episodes. [6, 8] If oceanic conditions were stable from year to year, fish of a given year class would migrate farther and farther northward each summer as they got older and larger. During El Nino episodes, when the waters off the Pacific coast are warmer than normal, more hake migrate farther north. During La Nina episodes, when the waters are cooler than normal, more hake stay to the south. [6, 8] Thus, if the stock were dominated by a young year class during a La Nina, most of the hake would be expected to be off northern California and Oregon. Conversely, if the stock were dominated by an older year class during an El Nino, most of the hake would be expected to be off Washington and British Columbia.

El Nino and La Nina episodes often begin in June through August, reach peak strength in December through April, and begin to die out in May through July of the next year. They usually last 9 to 12 months. [22] There have been several El Nino and La Nina episodes since 2000. Episodes have occurred during the summers of most even-numbered years but not during the summers of odd-numbered years, when the NMFS hake surveys have been conducted. [23] In 2001, a La Nina ended in early spring. In 2003, an El Nino ended in late winter. In 2005, an El Nino ended at the beginning of the year and a La Nina began in the fall. In 2007, an El Nino ended at the beginning of the year and a La Nina started in late summer. In 2009, an El Nino started during the summer. In 2011, a La Nina ended during the spring and another La Nina began in early fall. It seems that hake migration should have taken place during El Nino/La Nina neutral conditions during the NMFS hake survey years of 2001 through

2007. The El Nino that started during the summer of 2009 might have influenced the stock to move farther north. The La Ninas during 2011 might have influenced the fish to remain toward the south even though ocean conditions were neutral during the summer.

In 2001, 72% of hake biomass measured by the NMFS hake survey was found off northern California and southern Oregon (35.5°N to 43°N). [15] Another 12% was off northern Oregon (43°N to 45.75°). Age-2 fish of the 1999 year class comprised 50% of the biomass and 71% of the estimated number of fish. Some older fish were found off British Columbia, but many were within the main concentration off California and Oregon.

In 2003, hake were spread throughout most of their summertime range. Almost 40% of hake biomass measured by the NMFS hake survey was found off northern California and southern Oregon but about 20% was off northern Oregon, 20% off Washington (45.75°N to U.S.-Canada border) and 20% off Canada. [16] Age-4 fish of the 1999 year class comprised 60% of the biomass and 64% of the estimated number of fish. There were more older fish in Canadian waters than off California and Oregon but over 10% of the age-4 fish were off Canada.

In 2005, 40% of the biomass measured by the NMFS survey was found in Canadian waters; 63% of that biomass was comprised of age-6 fish of the 1999 year class. [17] The waters off northern California and southern Oregon had 34% of the measured biomass; 18% was off northern Oregon and only 8% was off Washington. The 1999 year class dominated in northern U. S. waters, but off northern California and southern Oregon, the biomass of age-2 fish of the 2003 year class was almost as large as that of the 1999 year class. The 1999 year class made up 48% of the estimated number of fish; twice as many as the 2003 year class.

In 2007, hake biomass measured by the NMFS hake survey was rather uniformly distributed from south to north: 36% was off northern California and southern Oregon, 17% off northern Oregon, 22% off Washington, and 25% off British Columbia. [18] Age-8 fish of the 1999 year class comprised 43% of the overall biomass and 56% of the biomass off Washington and British Columbia. Age-4 fish of the 2003 year class were spread throughout the region and comprised about 12% of the biomass. Age-2 fish of the 2005 year class dominated the stock off California and comprised almost 20% of the overall biomass. Age-2 fish comprised 42% of the estimated number of fish; age-4 fish comprised 10% and age-8 fish comprised 28%.

In 2009, very few hake were found in Canadian waters. [13] In U.S. waters, the NMFS hake survey found an almost continuous band of hake from about 43°N to 47°N. [19] Hake were sparse off

California. Only 12% of the hake were off northern California and southern Oregon, with 54% off northern Oregon and 32 % off Washington. Age-3 fish of the 2006 year class comprised about 25% of the stock, age-4 fish of the 2005 year class comprised just over 40% and age-6 fish of the 2003 year class comprised about 10%. Age-10 fish of the 1999 year class were still relatively numerous, comprising about 15% of the stock. Large numbers of Humboldt squid contaminated the acoustic data during the survey and made it difficult to accurately resolve age versus latitude.

The results of the 2011 NMFS survey have not yet been published, but some data have been presented to the PFMC. [3] The strongest concentrations of hake were off northern California (39°N-42°N). Weaker concentrations were off central Oregon to the U. S. Canadian border (44°N-48°N). Hake were sparse off southern Oregon and British Columbia. Age-3 from the 2008 year class comprised over half of the stock. Age-2 fish from the 2009 year class made up a significant fraction of the stock and age-4 to age-6 fish from the 2005-2007 year classes contributed small amounts.

The most recent La Nina dissipated in April 2012. As of June 7, 2012, NOAA's Climate Prediction Center says that there is a 50% chance of an El Nino developing in late summer or fall. [24] Therefore, ocean conditions are expected to be El Nino/La Nina neutral during the northward hake migration of 2012. Thus, the age-3 and age-4 hake that are expected to dominate the stock should probably not be skewed to the north or south by ocean conditions. The mean latitudinal locations of age-3 and age-4 fish for the 2001 through 2007 NMFS hake surveys were off northern Oregon (about 45°N) and central Washington (about 47°N), respectively. Assuming that neutral ocean conditions will cause the hake to be near their mean locations, the adult stock should be mostly off Oregon and Washington during the summer of 2012.

The depths over which Pacific hake feed during the summer are typically described as being the continental shelf and slope. [21] Hake trawling generally occurs over bottom depths from 100 to 500 m. [3] NMFS hake surveys in 1977 and 1980 found hake between 100 and 300 m, with most between 100 and 200 m. [25] A NMFS survey in 1992 found hake over bottom depths between 50 and 1000 m, with most between 100 and 150 m. [25] The 2011 NMFS hake survey detected hake over bottom depths between 100 and 1000 m, with most between 300 and 600 m. [20] Hake have been found over much deeper depths. The original NMFS hake surveys extended from bottom depths of 50 m to less than 500 m. In recognition that there were significant quantities of hake beyond 500 m, the 1995 survey, and all subsequent surveys, went out to 1500 m. In the era of foreign

and joint-venture fishing, hake were caught over bottom depths of up to 2000 m as much as 20 nm from the shelf break. [8, 25]

An acoustic scattering experiment conducted by Navy scientists off the West Coast in 1992 found hake well off shore in deep water at nine sites between 40°N and 48.5°N. [26] Bottom depths were nominally 1000 or 3000 m at most sites at distances from about 30 to 70 nm from shore. In 1995, hake were found as far as 100 nm from the coast. [27]

Although hake have been found from the continental shelf to depths as great as 3000 m, they are concentrated near the shelf break, probably between 100 and 600 m. The distance between the 200 m and 500 m contours in the experimental area is less than 20 nm, often much less. [2] The NRL acoustic system is restricted from operating in water shallower than 200 m. Given the experimental objectives, the ship will probably operate as close to the 200 m contour as is feasible. Therefore, the ship, and the NRL acoustic system, will most likely be operating over bottom depths where hake concentrations are normally most dense.

SUMMERTIME DEPTH DISTRIBUTION OF PACIFIC HAKE

Pacific hake are classified as a "Groundfish" by the fisheries community, which implies that they live on or near the bottom. In early NMFS hake surveys both midwater and bottom trawls were used. Midwater trawls were used over bottom depths of about 50 to 460 m and bottom trawls were used over depths of about 50 to 370 m. [25] Hake are commercially fished with midwater trawls, not bottom trawls, which implies that concentrations of hake are well off bottom.

Data on hake depths are collected on every ping that detects hake during a NMFS hake survey. However, since fish depth is of no consequence in predicting abundance, depths are seldom, if ever, published in survey reports. Thus, information on hake depths must be found elsewhere.

An independent analysis of acoustic data from the NMFS 1992 hake survey found that hake depths during the day ranged between 50 and 500 m and averaged about 175 m. [28] (The 1992 survey track lines ran from bottom depths of 50 to 460 m. Hake depths of 500 m might have been recorded as the ship was maneuvering over deeper water between tracks.) Hake were not deeper beyond the shelf break, being between 150 and 250 m deep. [28]

Another study found that hake are densely concentrated between 100 and 250 m during the day and that at night they disperse and rise toward the surface. [29]

These two studies [28, 29] are focused on shelf and slope waters. The depths reported indicate that hake in shelf waters could be close to the bottom. However, hake are far above the bottom in deep water. [26] The 1992 Navy experiment found that layers of hake were 100 to 600 m deep during the day and 50 to 550 m deep at night over bottoms between 900 and 3100 m deep. The top of the daytime layer generally migrated upward at dusk but the bottom of the layer changed very little. Layer depths were not related to bottom depths.

If the NRL acoustic system operates near the 200 m contour, concentrations of hake in the area will probably range from depths of about 50 or 100 m to near the bottom during the day and closer to the surface at night.

AGGREGATIONS OF PACIFIC HAKE

Aggregations of hake are typically very large. During the 2011 NMFS hake survey, aggregations as long as 22 nm were detected. About 2/3 of the aggregations were between 1 and 6 nm long and about 30% were between 6 and 14 nm. Thicknesses of these aggregations ranged from about 25 to 250 m. About 3/4 were between 50 and 175 m thick. These dimensions were along the east-west tracks of the survey, essentially across the shelf and slope. [20]

The terminology describing aggregations of hake appears to be inconsistent. Hake aggregations are called layers in NMFS hake survey reports. [e.g., 16] In a review paper, the authors, all of whom were authors of Ref. 16, state that hake "form well-defined pelagic schools". [6] A paper analyzing the summertime distribution of hake discusses clusters of schools. [28] It is most likely that all the terms are describing the same aggregations. In the strict sense, a fish school consists of a group of similarly-sized fish, all swimming synchronously in the same direction. [30] In the general sense, a school may be any group of fish. It is highly unlikely that all the fish in a 5 to 10 nm long aggregation are all swimming synchronously in the same direction. Hence, aggregations of this size are probably not schools in the strict sense. (Think of the probability of a 2000 member high school marching band with everyone in step.) A more proper term for these large groups is a shoal. [30] The question then is: when is a large group of hake a shoal and when is it a layer? The answer probably depends on the context. Thus, when NMFS scientists are conducting a hake survey they are concentrating on getting their trawl at proper depth, into the layer of hake. But when an acoustic transect is finished and there are sections of the transect where hake were detected and sections where they were not, it seems natural to consider the patches of hake as schools (shoals).

The 1992 Navy experiment conducted measurements while the ship drifted about 1 nm, with little variation over that distance. Hence, the hake were considered to be in uniform layers in deep water. [26] Hake layers were about 175 to 500 m thick during the day and about 375 to 500 m at night. Average day and night layer thicknesses were 350 and 450 m, respectively. The strongest parts of the layers were about 100 to 150 m thick during the day and 200 to 300 m thick at night.

The independent analysis of the 1992 NMFS survey data interpreted small areas of high scattering as schools and clusters of schools. [28] The small section of echogram published in the paper shows areas of strong scattering within a non-uniform layer. These areas are definitely small enough to be actual schools. There were about 57 schools in a 3.5 nm transect segment. They were about 190 to 280 m deep. In the conduct of the survey, these schools would have been considered scattering "hot spots" and just integrated with all other scattering along the transect.

A study of the operations of factory trawlers showed that they tend to fish on hake aggregations that are 10 to 15 nm in size that can be trawled multiple times. When they finish in one area, they tend to 15 nm or more to a new location. [31] This implies that large aggregations of hake are 15 nm or more apart.

Operations near the 200 m contour can expect to encounter shoals of hake that extend for 1 to 10 nm. These shoals should be from about 50 m deep to near the bottom during the day and extend closer to the surface at night. The shoals could contain numerous small schools that could produce clutter for acoustic experiments.

SUMMARY

Pacific hake is a very abundant semi-pelagic species along the West Coast of North America. There is a major fishery for hake; the annual catch of hake exceeds that of any other species along the West Coast.

Pacific hake spawn off California early in the year and migrate northward in the spring. During the summer, adult hake are found from northern California to British Columbia. The north-south distribution of the hake stock during the summer depends on the size of the fish and ocean conditions. Older, larger fish swim farther north than younger, smaller hake. The hake stock is dominated by strong year classes and, as the year class ages, the average summertime location of the stock shifts northward. All adults swim farther north under warm, El Nino, conditions than they would under average conditions. Under cool, La Nina, conditions, they stay more toward the

south. The most recent La Nina dissipated in April 2012 and neutral ocean conditions are predicted for the summer of 2012.

There was an extremely strong year class in 1999. This year class dominated the stock from 2001 through 2007. In the summer of 2012, the stock is expected to be dominated by age-4 and age-3 fish from the 2008 and 2009 year classes. These fish should be about 40 cm long. There will probably also be some age-5 to age-7 fish, about 45 cm long. Based on the age and size of the fish and neutral ocean conditions, the stock will probably be mostly in waters off Washington and Oregon.

Pacific hake extend along the shelf and slope into water depths greater than 3000 m. Most are concentrated near the shelf break, in waters from 100 to 600 m deep. On the shelf, hake extend from about 50 m to near the bottom during the day and move nearer to the surface at night. Hake are between about 150 and 250 m deep over the slope. In deep water, hake were well above the bottom, extending from about 100 to 600 m during the day and 50 to 550 m at night.

Hake form large aggregations, or shoals, with horizontal dimensions from about 1 nm to greater than 15 nm. Over the shelf and slope, these shoals are about 15 nm apart. These shoals are not uniform and denser clumps within a shoal might produce clutter when insonified. Over the shelf and slope hake aggregations are primarily between 50 and 175 m thick. In deep water, average day and night layer thicknesses are 350 and 450 m, respectively.

In the summer of 2012, when the hake stock is expected to be centered off Washington and Oregon, an acoustic experiment conducted near the 200 m contour off Washington and Oregon can expect to encounter hake. It might be possible to find patches between large hake aggregations that are free of hake. Since hake are expected to be deeper than 50 m during the day and sardines are expected to be in the upper 20 to 30 m, it may be possible to differentiate the species by depth. The other option is to look for clutter in scattering from hake shoals.

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Table 1 - Median lengths of Pacific hake at age

AGE	FEMALES 1975-1989	MALES 1975-1989	FEMALES 1990-2010	MALES 1990-2010
1	26	26	22	22
2	34	34	34	34
3	39	39	40	39
4	42	41	43	42
5	44	43	45	44
6	46	44	46	45
8	51	49	48	46
10	55	52	50	48
12	58	54	50	48
15	61	55	51	48

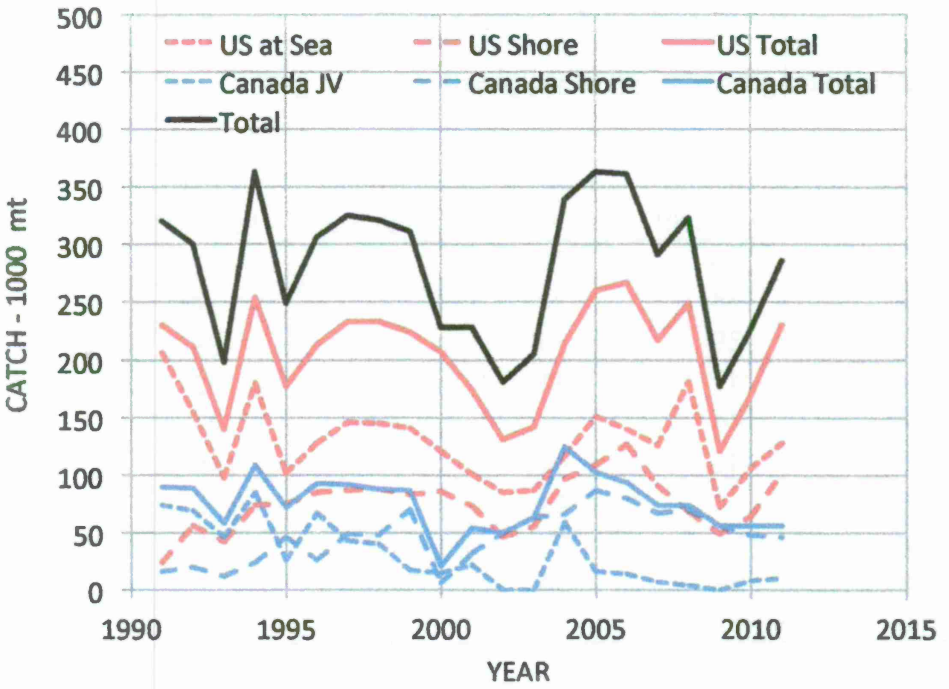

Figure 1 - Catches of Pacific hake

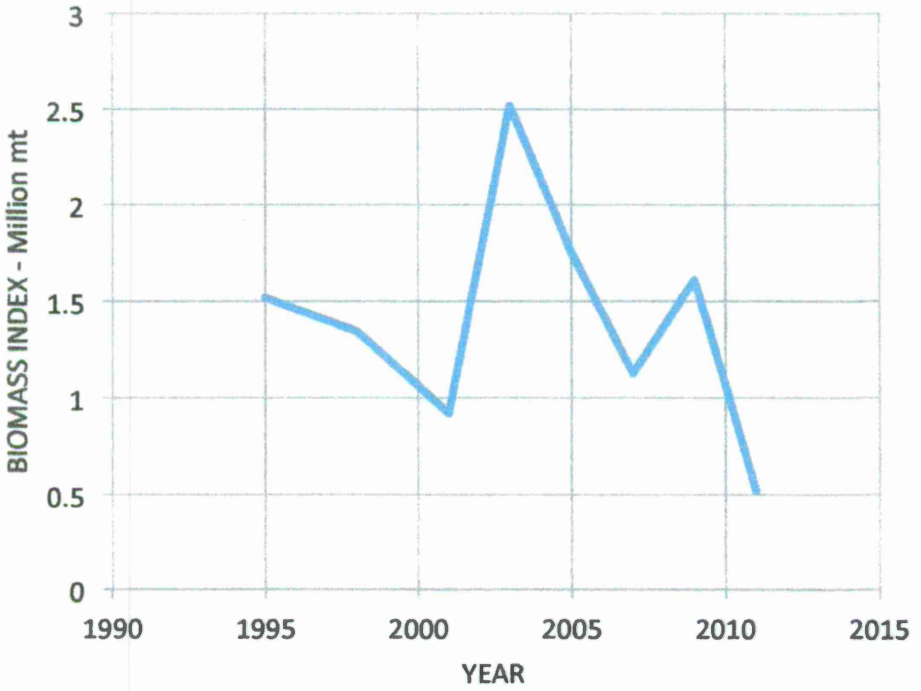

Figure 2 - NMFS hake survey biomass index

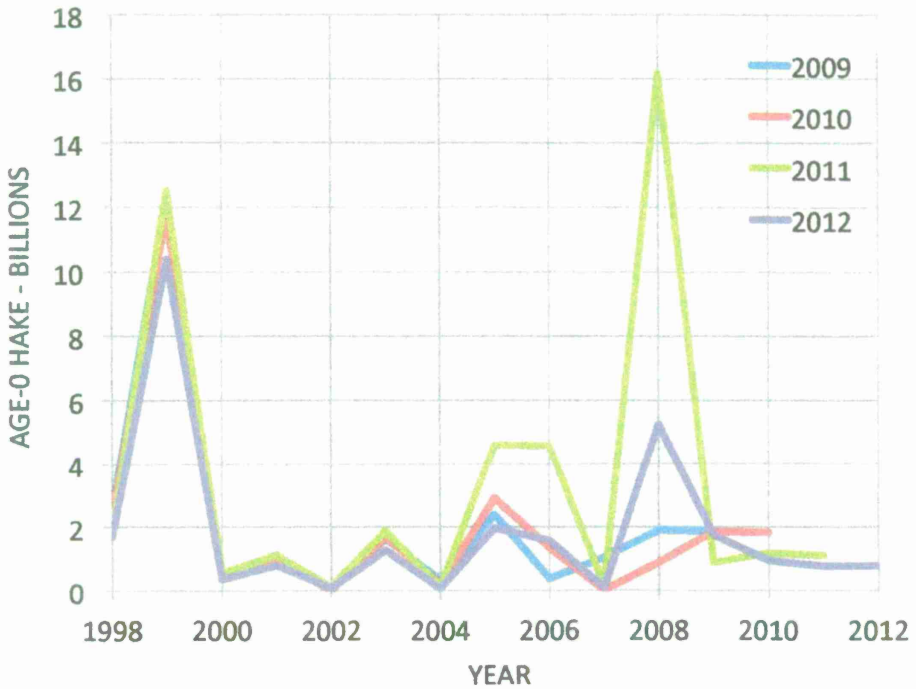

Figure 3 - Estimated numbers of age-0 Pacific hake

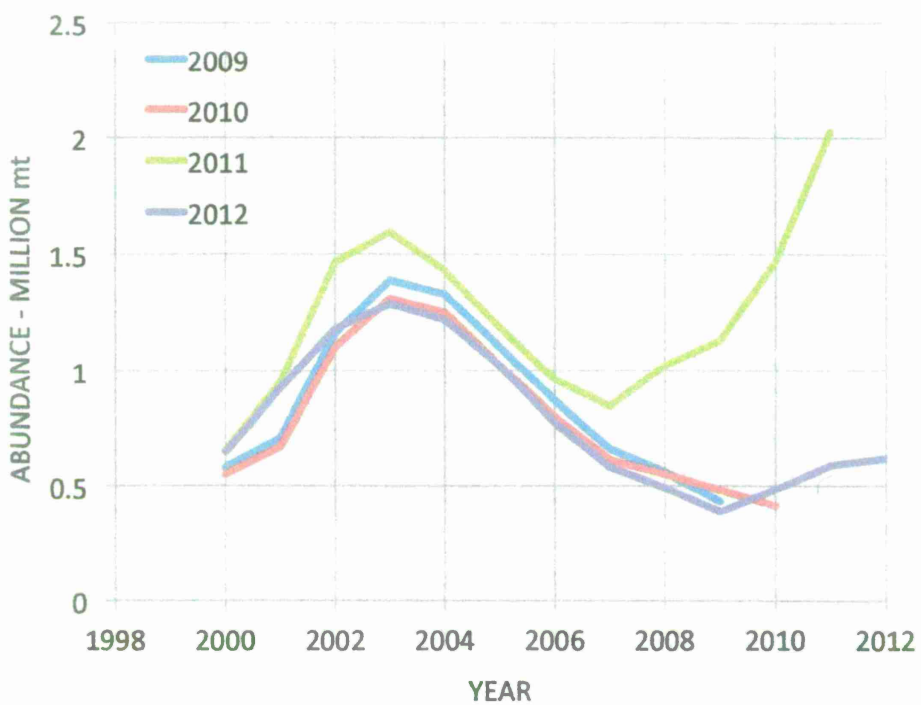

Figure 4 - Estimations of Pacific hake spawning female abundance